EC307: Mobile Communication and Networks

Module 5: Multiple Access Techniques

1 Introduction

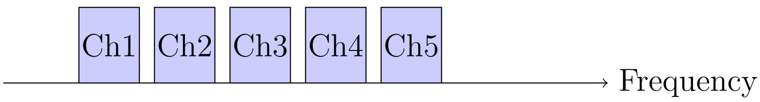
In a communication system, **multiple access** refers to the technique by which multiple users share the same communication channel (frequency band, time slot, or code) efficiently without interference. The objective is to maximize **spectrum utilization**, minimize interference, and ensure fair access to all users.

2 Types of Multiple Access Techniques

2.1 Frequency Division Multiple Access (FDMA)

Concept: The total available bandwidth is divided into distinct frequency channels. Each user is assigned a dedicated frequency band for the duration of communication.

Diagram:



Characteristics:

- Simple to implement.
- Requires guard bands between channels.
- Less efficient for bursty data.

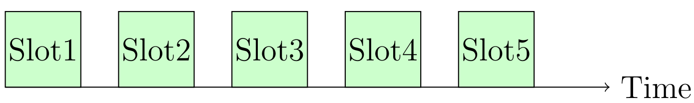
Example: Suppose a total bandwidth of 30 MHz is divided into 30 channels of 1 MHz each (including a 0.05 MHz guard band).

$$\text{Usable bandwidth} = 30 \times (1 - 0.05) = 28.5 \text{ MHz}$$

$$\text{Efficiency} = \frac{28.5}{30} \times 100 = 95\%$$

2.2 Time Division Multiple Access (TDMA)

The available frequency band is shared in time. Each user transmits in their assigned **time slot** in a repetitive frame structure.



Characteristics:

- Requires synchronization between users.
- Used in GSM (2G) systems.
- Guard times are needed to prevent overlap.

Example: If one TDMA frame has 8 time slots and the frame duration is 4.615 ms, then

$$\text{Slot duration} = \frac{4.615}{8} = 0.577 \text{ ms}$$

Thus a typical TDMA system parameter set used in GSM (as an illustrative example) is:

$$\text{Frame duration } T_f = 4.615 \text{ ms}, \qquad \text{Slots per frame } N_s = 8.$$

Thus the frame repetition rate is

$$f_f = \frac{1}{T_f} = \frac{1}{4.615 \times 10^{-3}} \approx 217.391 \text{ frames/s}.$$

TDMA Burst Types (GSM examples)

TDMA systems use different burst formats for different purposes. Common GSM burst types are:

Normal Burst (NB): used for traffic and many control channels.

Frequency Correction Burst (FB): used by mobiles to correct their local oscillator frequency.

Synchronization Burst (SB): used to obtain frame timing and cell identity.

Access Burst (AB): used for random access from a mobile — longer useful part to accommodate timing uncertainty.

Dummy/Idle Bursts: used when no data is sent.

Below we give the widely-used **Normal Burst** structure in detail (GSM-style) because it illustrates all important fields.

Normal Burst structure and fields

A Normal Burst (NB) is composed of the following fields (bit counts are *bit-times* at the symbol/bit rate used on the radio interface):

$$\underbrace{3}_{\text{Tail bits}} + \underbrace{57}_{\text{Data (first part)}} + \underbrace{1}_{\text{Stealing flag}} + \underbrace{26}_{\text{Training sequence}} + \underbrace{1}_{\text{Stealing flag}} + \underbrace{57}_{\text{Data (second part)}} + \underbrace{3}_{\text{Tail bits}} + \underbrace{8.25}_{\text{Guard period}}.$$

Explanation of fields:

- **Tail bits (3 each end):** bits set to '0' used to flush the convolutional encoder to a known state. They allow the receiver to terminate trellis decoding cleanly.
- **Data (57 + 57 = 114 bits):** user or control data payload in the burst before channel coding / interleaving. Note: after channel coding the actual user information carried may be fewer bits.
- **Stealing flags (1 bit each):** indicate whether the corresponding data block is replaced by FACCH (fast associated control channel) signalling (i.e., used to steal the slot for control messages).
- **Training sequence (26 bits):** a known pattern used by the receiver for channel estimation (equalization) and coherent detection.
- **Guard period (8.25 bit-times):** gap at the end of slot to accommodate timing advance and prevent overlap between adjacent timeslots at the base station. The fractional 0.25 arises from GSM symbol timing: each burst occupies 156.25 bit-times total.

Total bit-times: Summing integer fields:

$$3 + 57 + 1 + 26 + 1 + 57 + 3 = 148 \text{ bit-times}$$

plus guard period

$$148 + 8.25 = 156.25 \text{ bit-times per slot (typical GSM normal burst).}$$

Other burst types (brief)

- **Frequency Correction Burst (FB):** long constant sequence allowing coarse frequency adjustment. It occupies the whole time slot with a special pattern and no data.
- **Synchronization Burst (SB):** contains a long training-like sequence for frame timing and cell ID detection (higher energy, special midamble).
- **Access Burst (AB):** has an extended guard period to allow for larger uplink timing uncertainty from mobiles initiating access.

Spectral Efficiency (bps/Hz): formulation

If the RF carrier bandwidth is B_{carrier} (for GSM realistic example $B_{\text{carrier}} = 200$ kHz), the *raw* spectral efficiency (before coding/overheads outside the burst) is:

$$\eta_{\text{raw}} = \frac{R_{\text{carrier (raw)}}}{B_{\text{carrier}}} = \frac{N_s \times B_{\text{slot}} \times f_f}{B_{\text{carrier}}} \quad \text{[bps/Hz]}.$$

2.3 Code Division Multiple Access (CDMA)

Concept: All users occupy the same frequency band and time but are assigned unique spreading codes. Signals are spread using pseudo-random sequences, making them separable at the receiver.

Mathematical Representation:

$$S_i(t) = d_i(t) \times c_i(t)$$

where $d_i(t)$ = data signal and $c_i(t)$ = spreading code.

Advantages:

- High spectral efficiency.
- Resistance to interference and multipath fading.
- Soft capacity — users can dynamically share bandwidth.

Example:

$$c_A = [1, -1, 1, -1], \quad c_B = [1, 1, -1, -1]$$

To send any data say, 101 to user A the sequence will be

$$[(1, -1, 1, -1), (-1, 1, -1, 1), (1, -1, 1, -1)]$$

To send the same data (101) to user B the sequence will be

$$[(1, 1, -1, -1), (-1, -1, 1, 1), (1, 1, -1, -1)]$$

2.4 Space Division Multiple Access (SDMA)

Concept: Users are separated spatially using directional antennas or beamforming. Multiple users can share the same frequency and time resources but in different spatial directions.

Applications:

- Used in MIMO systems and smart antennas.
- Core concept behind 5G massive MIMO.

2.5 Orthogonal Frequency Division Multiple Access (OFDMA)

Concept: Advanced version of FDMA where subcarriers are orthogonal to each other. The available spectrum is divided into narrow-band subcarriers assigned to users dynamically.

Applications: LTE, WiMAX, and 5G NR systems.

Example: If bandwidth = 10 MHz and subcarrier spacing = 15 kHz, then

$$N_{\text{subcarriers}} = \frac{10 \times 10^6}{15 \times 10^3} \approx 667$$

Comparison of Multiple Access Techniques

Technique	Advantages	Limitations
FDMA, e.g. AMPS	Simple, low delay	Guard bands reduce efficiency
TDMA, e.g. GSM	Efficient, digital	Needs synchronization
CDMA, e.g. IS-95, 3G	High capacity, secure	Complex receiver
SDMA, e.g. MIMO, 5G	Very high capacity	Requires smart antennas
OFDMA, e.g. LTE, 5G NR	High data rate, flexible	Sensitive to frequency offset

Numerical Examples

Below are worked numerical examples for each access technique. calculations are shown step-by-step.

FDMA example: number of channels from total bandwidth

Problem: Total spectrum $B_T = 25$ MHz. Each channel requires $B_c = 25$ kHz of signal bandwidth and a guard band $B_g = 5$ kHz. Find the number of channels N.

Solution:

$$\text{Bandwidth per channel (including guard)} = B_c + B_g = 25{,}000 + 5{,}000 = 30{,}000 \text{ Hz}.$$

Total bandwidth in Hz: $B_T = 25$ MHz $= 25{,}000{,}000$ Hz.

Now compute:

$$N = \frac{B_T}{B_c + B_g} = \frac{25{,}000{,}000}{30{,}000}.$$

Perform division digit-by-digit:

$$30{,}000 \times 800 = 24{,}000{,}000$$

Remainder: $25{,}000{,}000 - 24{,}000{,}000 = 1{,}000{,}000$.

$$30{,}000 \times 33 = 990{,}000$$

Remainder: $1{,}000{,}000 - 990{,}000 = 10{,}000$.

$$30{,}000 \times 0.333\ldots = 10{,}000 \text{ (approx.)}$$

So $N \approx 800 + 33 + 0.333\ldots = 833.333\ldots$. Taking the integer number of full channels:

$$\boxed{N = 833 \text{ channels (usable).}}$$

TDMA example: total user channels from total spectrum (GSM-like)

Problem: Total spectrum $B_T = 5$ MHz. Each carrier (RF channel) occupies 200 kHz. Each carrier supports 8 time slots (TDMA). Find total number of simultaneous user channels.

Solution: Convert to Hz:

$$B_T = 5{,}000{,}000 \text{ Hz}, \quad B_{\text{carrier}} = 200{,}000 \text{ Hz}.$$

Number of carriers:

$$N_c = \frac{B_T}{B_{\text{carrier}}} = \frac{5{,}000{,}000}{200{,}000}.$$

Calculate:

$$200{,}000 \times 10 = 2{,}000{,}000,$$

$$200{,}000 \times 25 = 5{,}000{,}000.$$

So $N_c = 25$ carriers.

Each carrier gives 8 time slots:

$$\text{Total user-channels} = N_c \times 8 = 25 \times 8 = 200.$$

$$\boxed{\text{200 simultaneous user channels.}}$$